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STRUCTURAL ANALYSIS OF HOPPER SUCTION DREDGER

Summary

In recent years dredging industry has developed itself significantly, consequently developing sophisticated and powerful ships known as dredgers. The vessels are extremely specialized and require special attention for design, construction and operation. The purpose of this paper is to present the structural analysis of 14 000 m^3 Trailing Suction Hopper Dredger. The calculations have been performed to analyze the stress and buckling behavior in the primary structure within the hopper region and to assess the stress concentration in way of the rounded corners of large openings. The aim was to achieve optimized structural scantlings especially in way of primary structure and large openings. Reduction of structural weight has been achieved due to the rational structural design procedure.

Key words: Trailing Suction Hopper Dredger, structural analysis, structural design

STRUKTURNA ANALIZA USISNOG JARUŽALA SA SKLADIŠTEM

Sažetak

Razvojem industrije jaružanja zadnjih nekoliko godina razvili su se složeni i sofisticirani brodovi – jaružala. Zbog svojih specifičnosti, ovi brodovi zahtijevaju poseban pristup osnivanju, projektiranju konstrukcije te kasnije i pri samoj eksploataciji. Cilj ovog rada je opisati strukturnu analizu usisnog jaružala sa skladištem kapaciteta 14000 m^3. Proračunom su provjerena naprezanja i deformacije u primarnim konstrukcijskim elementima te naprezanja u uglovima velikih otvora. Motiv provođenja analize je želja za racionalnom raspodjelom materijala i smanjenjem težine samog broda. Uspjeh strukturne analize i ušteda na težini postignuti su suvremenim pristupom projektiranju.

Ključne riječi: usisno jaružalo sa skladištem, strukturna analiza, projektiranje konstrukcije

1. Introduction

Dredging technology is defined as an erosion, transport and sedimentation process of soil or rock, which is brought about through human intervention and carried out with specially designed machines. The dredging industry has developed itself from locally oriented activity to maintain navigable waterways into a global industry involved in maintenance dredging, land reclamation, coastal and port construction, as well as offshore construction by making use of evermore sophisticated and powerful ships [1]. In general, dredgers come in two basic forms: mechanical and hydraulic.

Mechanical dredgers work by mechanically digging or gathering sediment from the bottom surface of a body of water typically through use of a bucket or clamshell. Types of mechanical dredgers are: bucket ladder dredger; grab dredger, dipper and backhoe dredger [2]. Hydraulic dredgers work by sucking up a mixture of sediment and water (known as slurry) from the bottom surface and then transferring the mixture through a pipeline to a desired location. Dredgers are used to move a wide variety of materials. Some examples are human waste, trash, gravel, and gold. Dredgers help to keep many of canals, ports, harbors, and marinas clean. Dredgers even help to restore beaches and land lost due to erosion. Hydraulic dredgers include plain suction dredgers, cutter suction dredgers and trailing suction hopper dredgers.

Trailing Suction Hopper Dredger (THSD), which is described in this paper, is self propelled vessel equipped with suction tube with which the soil is collected in itself (hopper) and variety of possible dumping the load (bottom doors, self emptying channels, etc).

THSD enabled a major step forward in productivity and efficiency of dredging due to invention of centrifugal pump and marked the start of land reclamation dredging, as the dredged material could be pumped (through vacuum suction) into the ship's cargo hold in order to off-load at designated location by means of dumping through the bottom doors (by gravity) or by pumping it overboard with powerful pump.

THSD are non-stationary dredgers which means that they are not anchored by wires or spud poles but are able to sail, work and maneuver under their own power. The normal working cycle of vessel can be broken down into four basic functions:

- extracting material from below the water surface,
- containment of the material,
- transporting the material to another location,
- discharging the material,
- sailing back empty to the extracted area.

Area of application can be applied in almost all soils ranging from soft silt to sand or even mud or gravel. Extracting material from deeper (more distant water) and depositing material onshore straight from THSD requires longer, stronger suction tube and more powerful suction pump, longer and faster vessel and suction discharging installation. This is the reason of the evolution of a new breed of THSD. Overview of THSD fleet is presented in [2].

2. Structural aspects of Trailing Suction Hopper Dredgers

Since Uljanik Shipyard has signed contract with one of the leading owner of dredgers, for building two Trailing Hopper Suction Dredgers, design department was persistent in the idea that the rational structural design and decreasing thickness of material is a design priority. In order to achieve that aim, Yard has taken into consideration structural aspects of TSHD. It is noted that, as consequence of the fact that the structural arrangement of dredger involves discontinuities, particular care is to be taken to avoid cracks or fractures. The rules of classification societies for design and construction of ships provide general structural design principles, considering a large number of dredger related issues, including:

- structural reinforcements at location where the hull is heavily stressed,
- requirement for rounding of the cut-outs in the bottom plating with a radius as large as possible, in particular near the bottom doors (high stress concentrations and risk for occurrence of fatigue cracks).

More detailed requirements are provided for longitudinal and transverse members in the hopper wells. Particularly important are the structural integration of the hopper into the fore and aft ends. Requirements for the structural arrangement near the suction pipe inlets are provided, addressing structural continuity and reinforcements, as well as stiffening of knuckles and welding. Requirements for structural reinforcements at the location of drag head are also prescribed, as well as for the outfitting of the suction pipes for handling and securing.

Main particulars of the TSHD analyzed in the present study are provided in ref. [4]. It should be mentioned that the whole ship structure in cargo hold area is made of high tensile steel with yield strength of 355MPa. Exceptions are local reinforcements around large opening made of special steel with yield strength of 490MPa.

Longitudinal strength calculation is performed by Uljanik design department according to the Rules of classification society – Bureau Veritas (BV). Standard software for rule calculation – Mars 2000, has been used as shown in Fig.1. The preliminary calculation of the primary supporting members has been made according to BV Rules Pt.B, Ch.7, Sec. 3.5.2. Yield check was preformed through an isolated beam structural model [3], where NAUTICUS 3D beam software has been used (Fig.2). In case of a Hopper Suction Dredger, three dimensional FE model is needed according to the BV Rules Pt.B, Ch.7, Sec. 3.1.1.2 [3]. Scantlings of plates, longitudinals and secondary stiffeners based on Yard calculation, have been used as input data for the FEM model.

3. 3D finite element analysis

Finite element (FE) analysis is preformed in three phases:

1. coarse mesh analysis,
2. fine mesh analysis,
3. very fine mesh analysis of stress concentration.

VeriSTAR Hull 2 software is employed in the FE analysis [5]. Calculations have been performed in net scantling. Net scantlings are obtained by reducing “as-built” thickness by BV rule corrosion deduction thickness and also by additional thickness allowances provided by Owner. Following loading condition is used in the analysis, complying with the BV rules:

- draught of 11.1 m in dredging condition,
- structural self-weight using acceleration of 9.81 m/s^2,
- density of δ=1.7m/t^3 for spoil,
- density of δ=1 m/t^3 for HFO with setting pressure p=0.2 bar.

Still water dredging loading condition is combined with dynamic loads due to the waves according to BV rules. Load case known as “B” from BV rules is employed in the study. Parameters as still water pressure, internal dynamic pressure, partial safety factors, total vertical bending moment (M_{tot} = -1 416 692 kNm) are all calculated according to the BV rules.

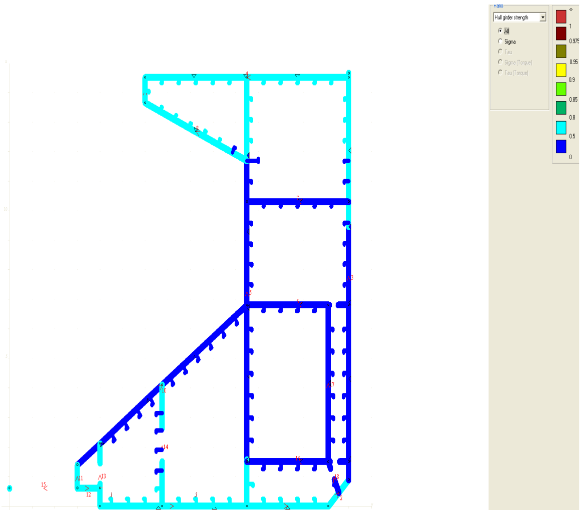

Fig. 1 Longitudinal strength in Mars BV software
Slika 1. Uzdužna čvrstoća u programu Mars BV

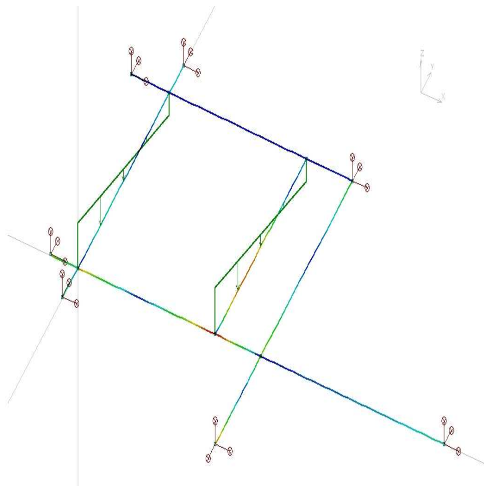

Fig. 2 Isolated frame in NAUTICUS 3D software
Slika 2. Izolirani okvir u programu NAUTICUS 3D

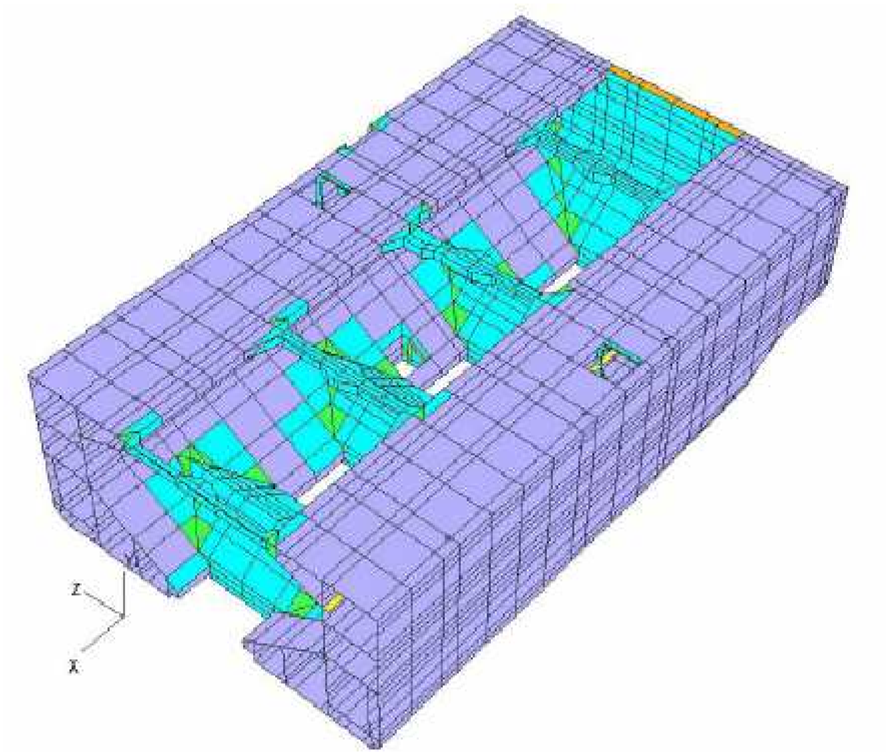

Fig.3. 3D FE model of cargo area
Slika 3. 3D model konačnih elemenata teretnog prostora

3.1. Coarse mesh analysis

Firstly, the ship structure between ER and FP bulkheads (FR.35-FR.101) is modeled by the coarse finite element mesh. This model is used to represent the global behavior of the primary structure, see Fig.3.

Boundary condition are assumed such that the model is fixed at its fore end, while at the aft end, vertical and horizontal shear forces and bending moments are applied to ensure the equilibrium of the model. The aft end section remains free as the transverse bulkhead at Fr.35 ensures rigid constraints in such way that the section remains plane after deformation.

Hull girder loads are applied on structural elements contributing to the longitudinal strength at the aft end of the model. These loads are applied in a way to achieve maximal bending moment at the middle of the model (Fr.65). Load balancing procedure in VeriSTAR Hull is preformed automatically, while technical details of the balancing procedure are provided in the BV Rules [3]. Concentrated forces are taken in to account according to the yard documentation. Deformation of the model after applying distributed pressure loads, concentrated forces, boundary condition, etc. is shown at Fig.4. It should be noted that deformation plots as Fig.4 are provided only for the purpose of checking the model, while no specific additional requirements are prescribed for allowable deformation levels.

The buckling strength is checked according to BV Rules. The stress levels are analysed according to the von Mises stress criterion. Overview of von Mises stresses at different part of structure shown in Fig.5. The buckling level are analysed using:

- Uni-axi compression,
- Shear,
- Flexural, compression & shear,
- Bi-axial compression.

Permissible von Mises stress for the coarse mesh reads (BV Rules Pt. B, Ch.7, Sec.3):

$$\frac{Ry}{\gamma_R \gamma_M} \geq \sigma_{VM}$$

By introducing partial safety factors $\gamma_R = 1.20$ and $\gamma_M = 1.02$, yielding check criterion reads 266 MPa $\geq \sigma_{VM}$.

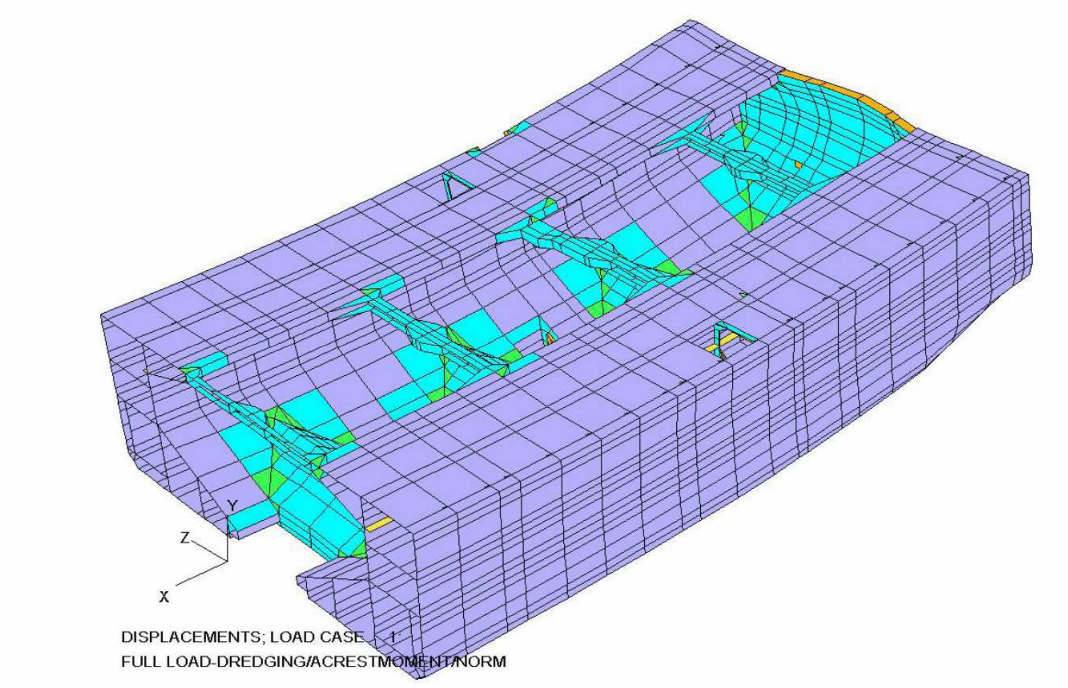

Fig.4. 3D coarse mesh model deformation

Slika 4. Deformacija 3D modela konačnih elemenata

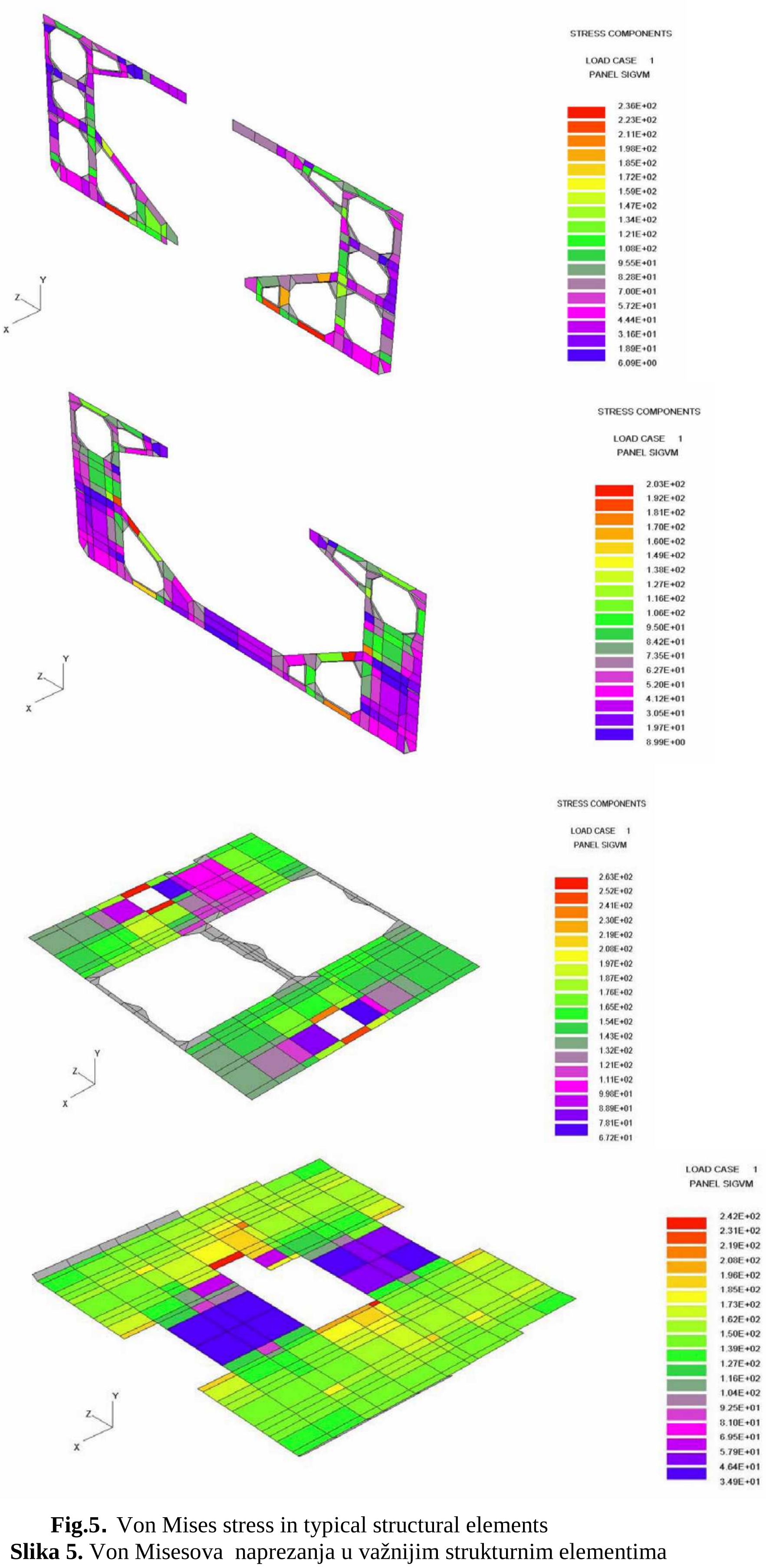

Fig.5. Von Mises stress in typical structural elements
Slika 5. Von Misesova naprezanja u važnijim strukturnim elementima

Results are assessed only in the middle part of the model (Fr.47-Fr.83) in order to avoid unrealistic influence of the boundary condition. The results have showed few suspect elements roughly indicating to the yard which parts of the structure should be reinforced. The critical elements are mostly plating of web frame structure having relatively small web height because of a need for large openings enabling accommodation of pipes and other equipment. Webs are consequently exposed to the rather unfavorable high shear stresses. These suspect elements are additionally checked by the fine FE mesh in the second phase of the analysis.

3.2. Fine mesh analysis

In the second phase of the analysis, the hull structure between Fr.61 and Fr 73 is modeled by the “fine mesh” of finite elements in order to obtain more accurate stress distribution (Fig.6). The main purpose is to analyze the structural behavior of the typical web frame in PS (Fig.7a), and of the structure in way of the shallow water door at SB (Fig.7b). The principle of this refined model is that displacements of the coarse mesh model are used as boundary conditions. The fine mesh model is thus forced to the same displacement pattern as the coarse model corresponding to the ship global deformation. On top of this, all local pressures loads and concentrated forces are included in the model, producing thus local stresses. The mesh size of the fine mesh FE model is in principle equal to the stiffener spacing. However, webs of primary members subjected to the bending loads should be refined in at least three elements along web height in order to get credible stress distribution.

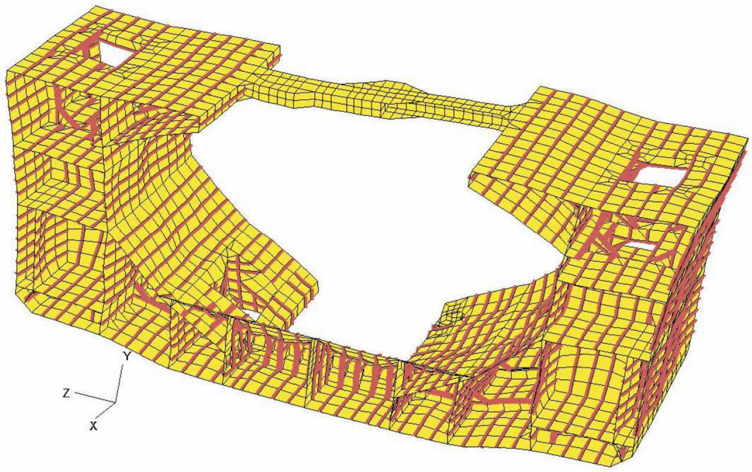

Fig.6. 3D fine mesh model deformation
Slika 6. Deformacija modela fine mreže konačnih elemenata

Permissible stress for the fine mesh read (BV Rules Pt.B, Ch.7, Sec. 3.4.3.):

$$\frac{Ry}{\gamma_R \gamma_M} \geq \sigma_{VM} , \quad \frac{Ry}{\gamma_R \gamma_M} \geq \max(|\sigma_1|,|\sigma_2|) , \quad 0.5\frac{Ry}{\gamma_R \gamma_M} \geq \tau_{12}$$

By introducing partial safety factors $\gamma_R = 1.05$ and $\gamma_M = 1.02$, yielding check criterion reads:

$$305 \text{ MPa} \geq \sigma_{VM}, \quad 305 \text{ MPa} \geq (|\sigma_1|,|\sigma_2|) \text{ and } 152 \text{ MPa} \geq \tau_{12}$$

The results showed stresses concentrations around large openings in the main deck and ship bottom (Fig.7b), which are additionally analyzed by the very fine mesh in the third phase of the study.

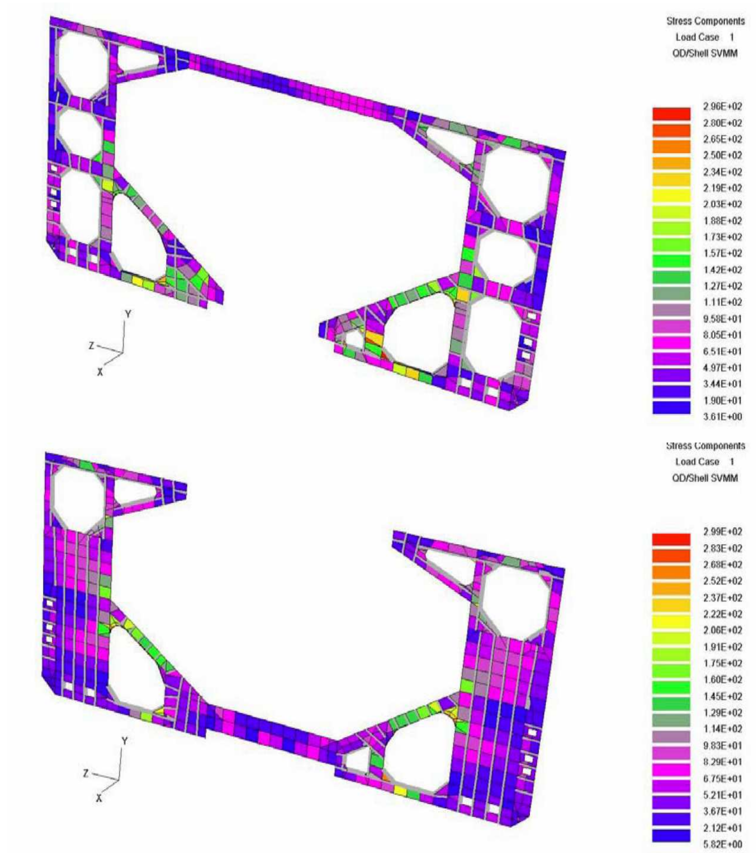

Fig.7a. Fine mesh von Mises stresses in typical web frame
Slika 7a. Von Misesova naprezanja u tipičnom okvirnom rebru

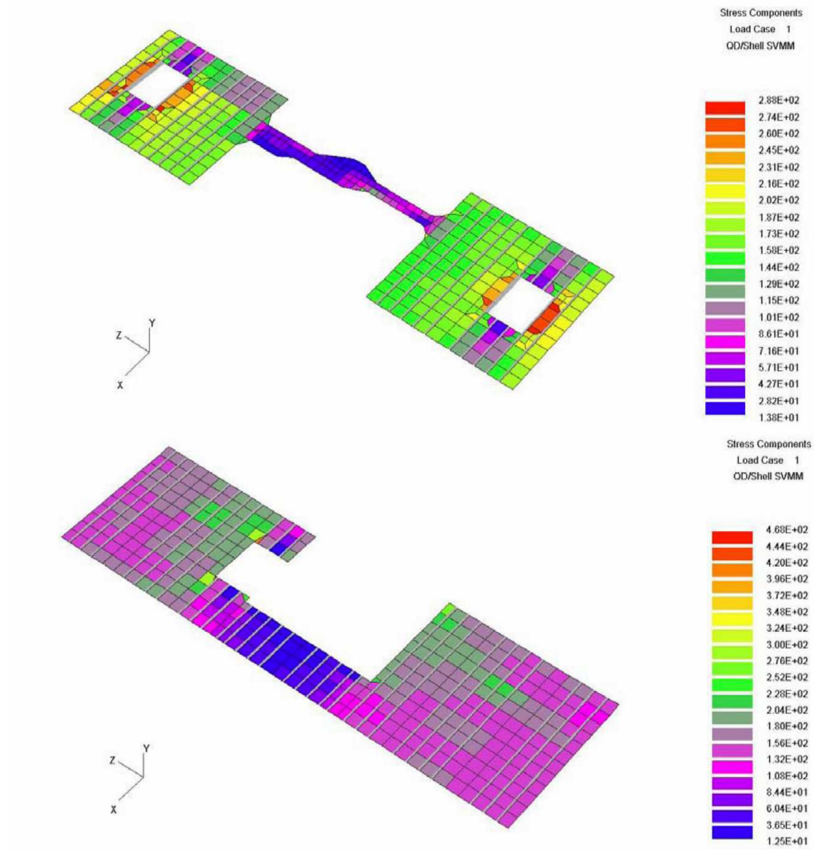

Fig.7b. Fine mesh von Mises stress IWO opening in the main deck and shallow water doors
Slika 7b. Von Misesova naprezanja u području otvora na glavnoj palubi i vratiju na dnu broda

3.3. Very fine mesh analysis

In the third phase of the study, the stress concentration in way of rounded corners of large openings in the bottom and the main deck between Fr.65 and Fr.69 is analyzed using very fine mesh of the finite elements. The model is presented in Fig.8. Mesh size around opening corners reads about 50x50 mm, as shown in Fig.9. On the bottom shell, two openings are considered: the main and shallow water door openings. Special high tensile steel DH49 with yield stress 490MPa is employed for inserts in way of the corners of the bottom door openings.

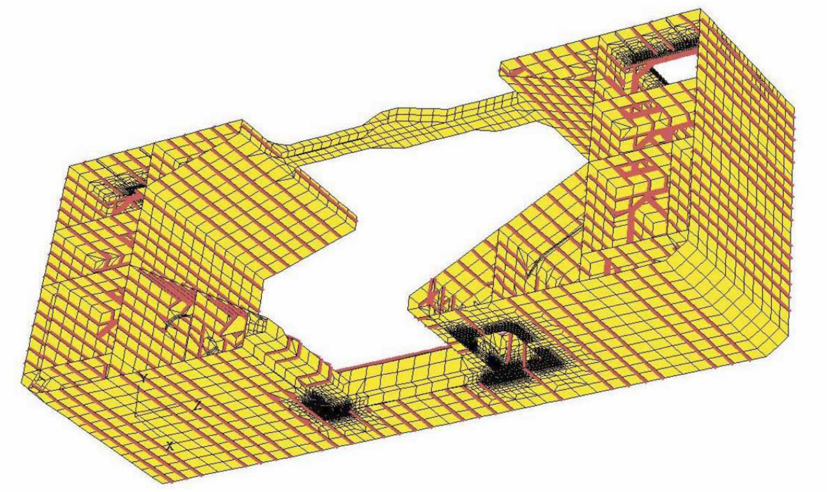

Fig.8. 3D very fine FE model
Slika.8. 3D model jako fine mreže KE

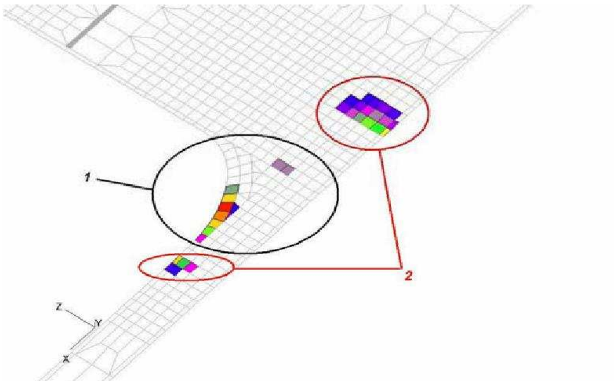

Fig.9. Highly stressed areas in the very fine FE mesh
Slika 9. Područja povećanih naprezanja u modelu jako fine mreže

The permissible stresses are checked against von Mises stresses calculated at the middle plane of the element (Fig.9). Results show that the structure needs reinforcements in way of rounded corners both in the bottom and main deck area. Due to the prescribed geometry of the bottom doors, only local increase of thickness is considered as possible solution to the stress concentration problem. Some other possible structural solutions, as changes of radius or shape of corners are not considered in this study, although such solutions could also reduce stress concentration.

4. Conclusion

The paper describes structural analysis procedure of Trailing Hopper Suction Dredger. Based on the preliminary examination of the structure, before the FE analysis was performed, significant reinforcements of the primary transverse elements were required from the classification society. Only detailed FE analysis, as presented in the paper, could be acceptable alternative to prove structural adequacy. Consequently, significant saving in structural weight (estimated to around 200 t) has been achieved due to the rational structural design procedure.

The present work aimed to enable fast and efficient approval of classification drawings based on the calculation procedure which is completely in accordance to the rules of classification society. However, there is a scope for further improvement of the structural design by performing spectral fatigue analysis of highly stressed details. Also, because of the enormously high power of installed pumps and other equipment on dredging vessels, vibration and noise propagation analysis are very important. Such advanced analyses may be recommended in future development of similar projects.

Disclaimer

The opinions presented in the paper are those of the authors and should not be construed as reflecting the views of any institution.

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